Composite Materials for Space and Aeronautics Applications

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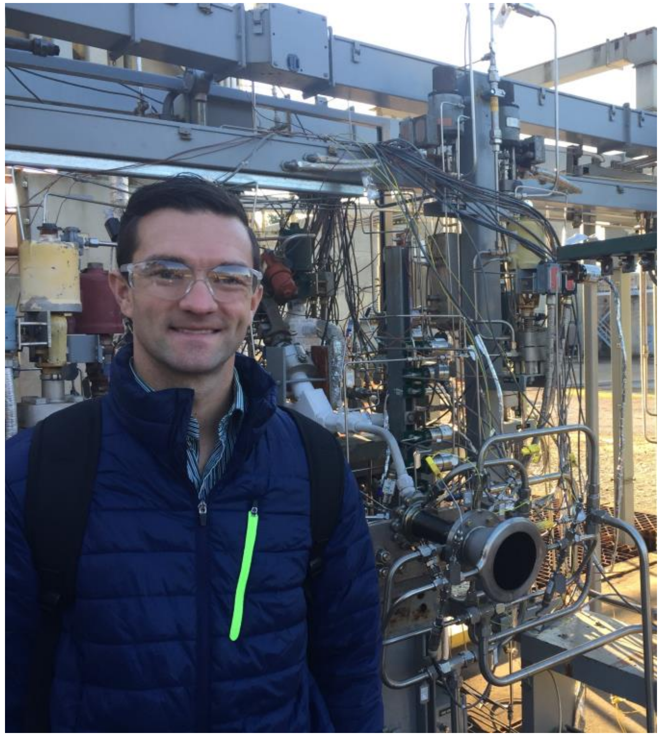
Outline

- Personal Introduction
- Organization Overview
- Projects
  - Rapid Analysis and Manufacturing Propulsion Technology (RAMPT)
  - AERoBOND: Incubation to Major NASA Aeronautics Project
  - Cure Process Monitoring of Composites
- Summary
- Questions

About Me

- Current Position:
  - Materials Research Engineer, NASA Langley Research Center (LaRC), 2018-Present
  - Research focus: Manufacturing and process monitoring of advanced aerospace composite structures
- How did I get here?
  - Graduate Research Assistant, National Institute of Aerospace (NIA), 2013-2017
    - Research performed on-site at NASA LaRC, 2014-2017
  - Internships: Boeing, Caterpillar, Duke Energy, Progress Energy
  - Education:
    - Ph.D. Aerospace Engineering, N.C. State University, 2017
    - M.S. Mechanical Engineering, N.C. State University, 2014
    - B.S. Civil Engineering, N.C. State University, 2012



Personal Spotlight

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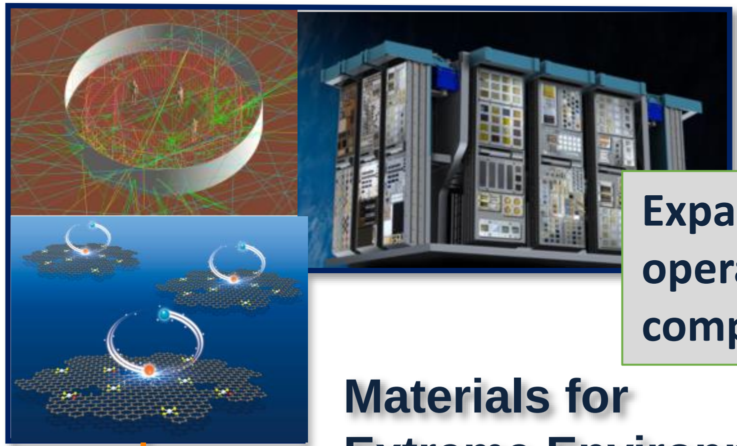
Advanced Materials and Processing Branch

Making the Materials of Tomorrow, Today



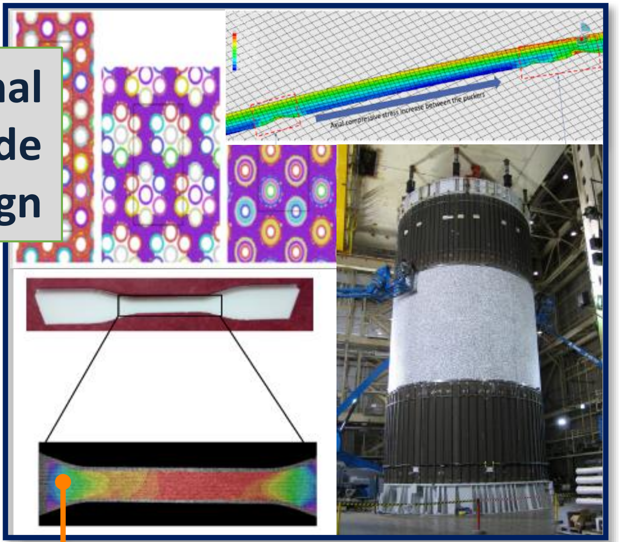
Expanding the range of operational environments of component technology

Materials for Extreme Environments

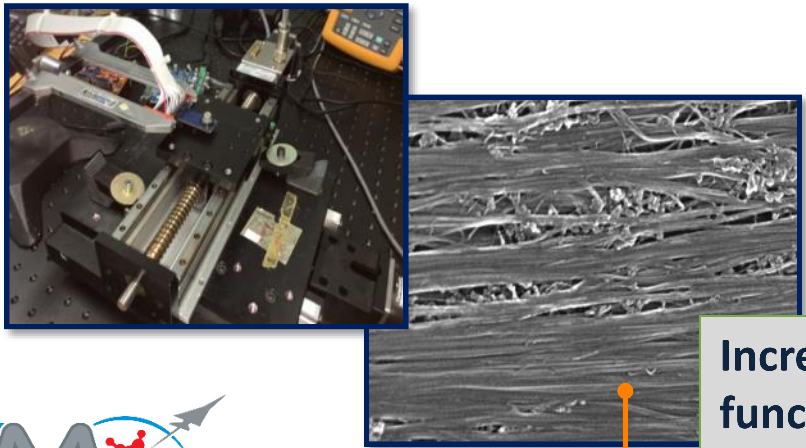
Developing and demonstrating advanced fabrication technology

Process Development

Developing validated computational models and simulations to guide materials design



Modeling and Simulation



Increasing performance and functionality of load bearing structures

Characterization

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Rapid Analysis and Manufacturing Propulsion Technology (RAMPT)

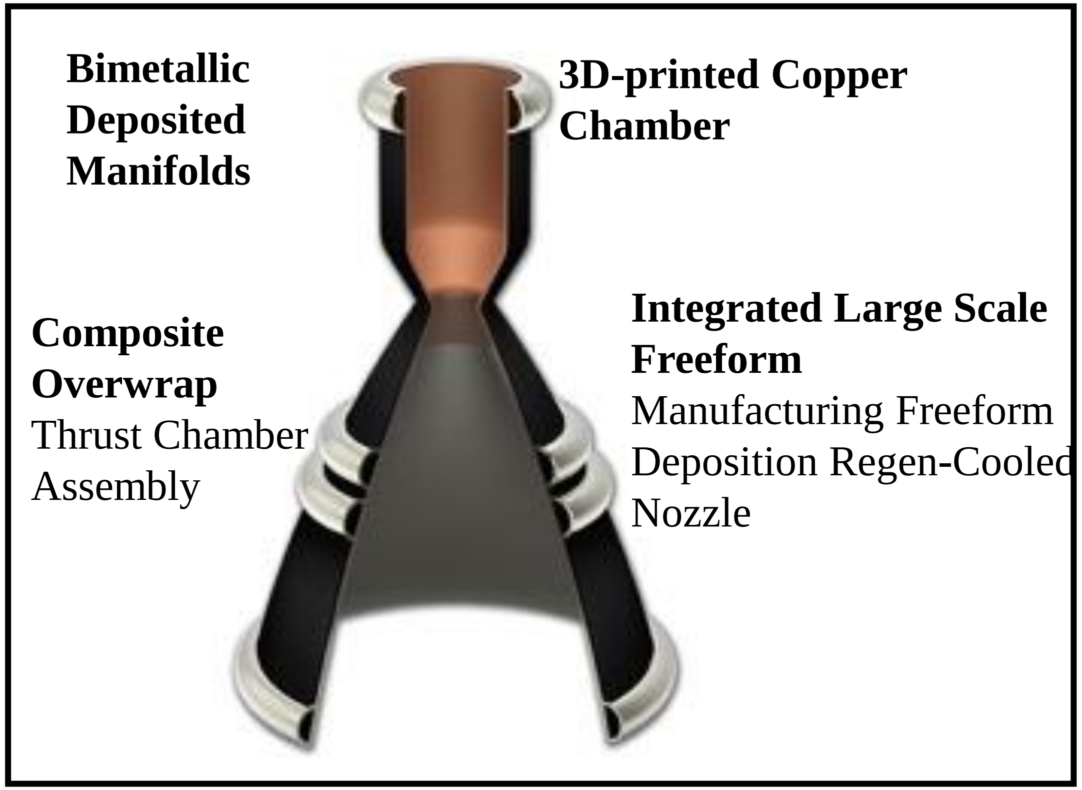
1. A.M. Clark, T.B. Hudson, C. Park, S.G. Miller, M. Goetz, and P.R. Gradl, "Composite overwrap lessons learned on 40k thrust chamber assemblies," *To be published in SAMPE Technical Conference Proceedings*, Seattle, WA, April 17-20, 2023.

2. A.M. Clark, T.B. Hudson, S.G. Miller, C. Park, C.S. Protz, "Lightweight thrust chamber composite overwrap lessons learned," *Composites and Advanced Materials Expo (CAMX) Proceedings*, Dallas, TX, October 19-21, 2021.

3. P.R. Gradl, C.S. Protz, J. Fikes, A. Clark, L. Evans, S. Miller, D. Ellis, and T.B. Hudson, "Lightweight thrust chamber assemblies using multi-alloy additive manufacturing and composite overwrap, *AIAA Propulsion & Energy Forum Proceedings*, New Orleans, LA, August 24-26, 2020.

Rapid Analysis and Manufacturing Propulsion Technology (RAMPT)

- Mature novel design and manufacturing technologies to ***increase scale***, significantly ***reduce cost***, and improve performance for ***regeneratively-cooled thrust chamber assemblies***
  - Highest-cost and longest-lead components on rocket engines
- Five Key Technologies:
  1. Powder bed fusion copper combustion chamber
  2. Freeform blown powder nozzle
  3. ***Composite overwrap structural jacket***
  4. Bimetallic radial deposition for manifolds
  5. Modeling and analysis tools for additive and regeneratively-cooled designs



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Hardware Overview

2k-lb$_f$ Thrust

Fuel Type: LOX/RP-1 and LOX/LH_2

Decoupled Chamber

Coupled Chamber

Engine Class: Reaction Control Thrusters

7k-lb$_f$ Thrust

Fuel Type: LOX/LCH_4

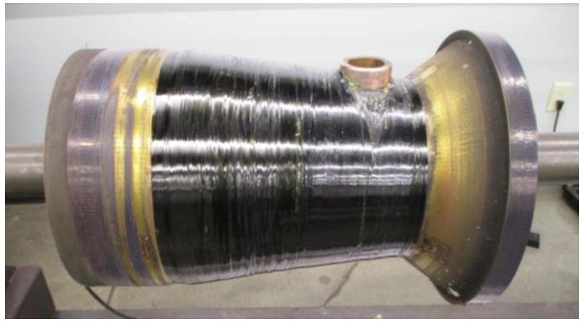
Decoupled Chamber

Coupled Chamber

Engine Class: Lunar (and Planetary) Landers

40k-lb$_f$ Thrust

Fuel Type: LOX/LH_2



Decoupled Chamber

Coupled Chamber

Engine Class: Launch Vehicle (Upper Stage)

LOX: Liquid Oxygen
RP-1: Rocket Propellant-1 (highly refined form of kerosene)
LH_2: Liquid Hydrogen
LCH_4: Liquid Methane

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Hot Fire Test Video
2k-lbf Thrust with LOX/RP-1

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AERoBOND: Incubation to Major NASA Aeronautics Project

1. F.L. Palmieri, T.B. Hudson, A.J. Smith, R.J. Cano, J.H. Kang, Y. Lin, L.J. Abbot, B. Clifford, I.J. Barnett, and John W. Connell, “Latent cure epoxy resins for reliable joints in secondary-bonded composite structures,” *Composites Part B: Engineering*, Vol. 231, p. 109603, 2021. https://doi.org/10.1016/j.compositesb.2021.109603

2. A.J. Smith, J.A. Salem, T.B. Hudson, and F.L. Palmieri, “Interlaminar mechanical performance of the latent-cure epoxy joint,” *Composites Part B: Engineering*, 2023.

Hi-Rate Composite Aircraft Manufacturing (HiCAM)

Challenge

- ❖Aerospace is America's largest export by dollar[1]
- ❖Boeing produces more 737s than any other commercial aircraft[2]
- ❖Will the single aisle replacement aircraft incorporate composite materials?
  - ❖Good specific properties
  - ❖Manufacturing challenges
  - ❖Need 80-100 shipsets per month

Objective

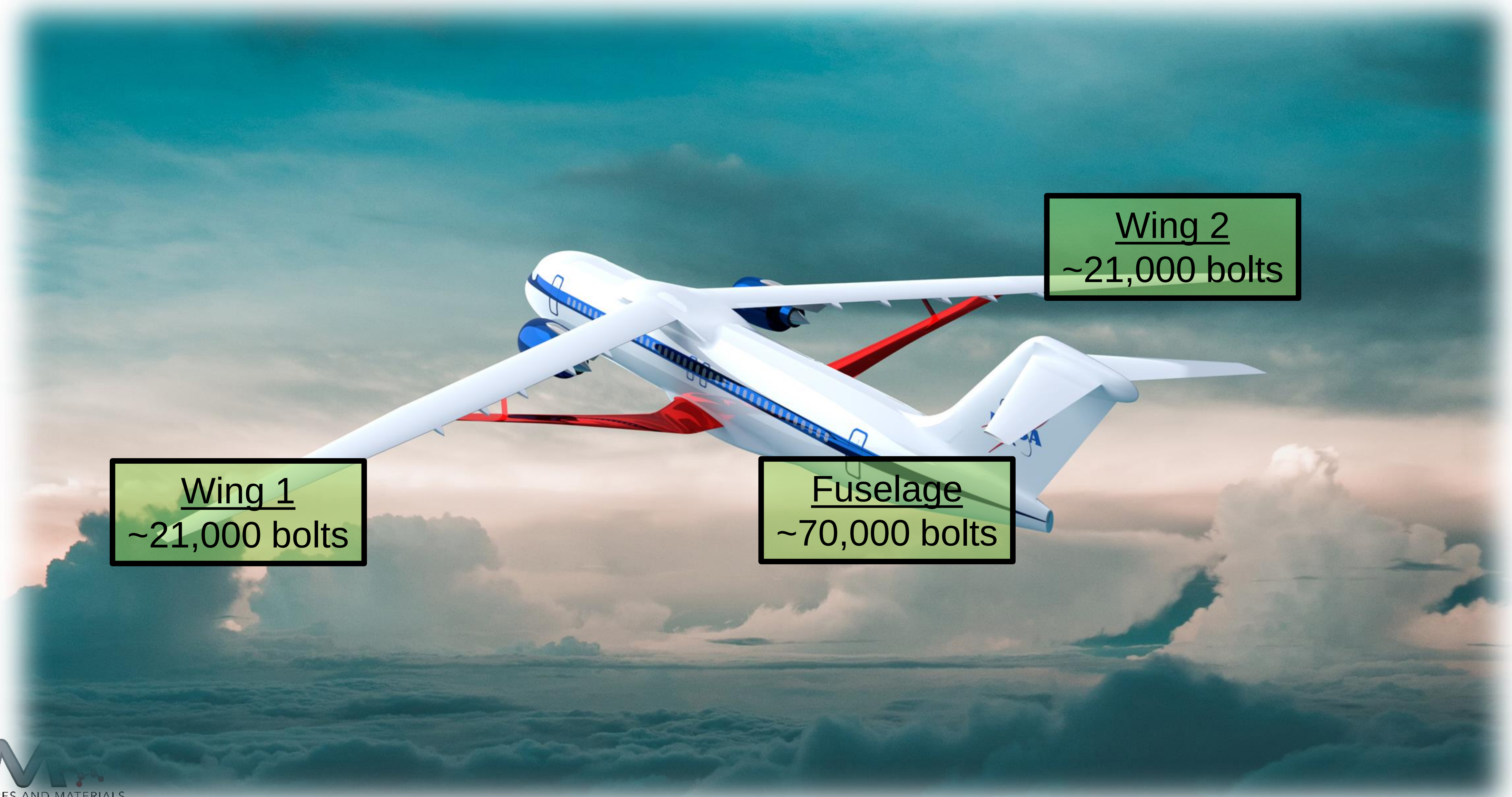
- ❖HiCAM aims to develop multiple composite manufacturing technologies to TRL 6-7 by 2027 to meet 80 shipsets/month (4 to 6 times current rate)

https://www.nasa.gov/sites/default/files/isaac_09overallworking.jpg

[1] https://www.thebalancemoney.com/u-s-exports-top-categories-challenges-opportunities-3306282#:~:text=Capital%20goods%20top%20the%20list%20of%20U.S.%20exports

[2] https://investors.boeing.com/investors/fact-sheets/default.aspx

Single-Aisle Commercial Transport Aircraft



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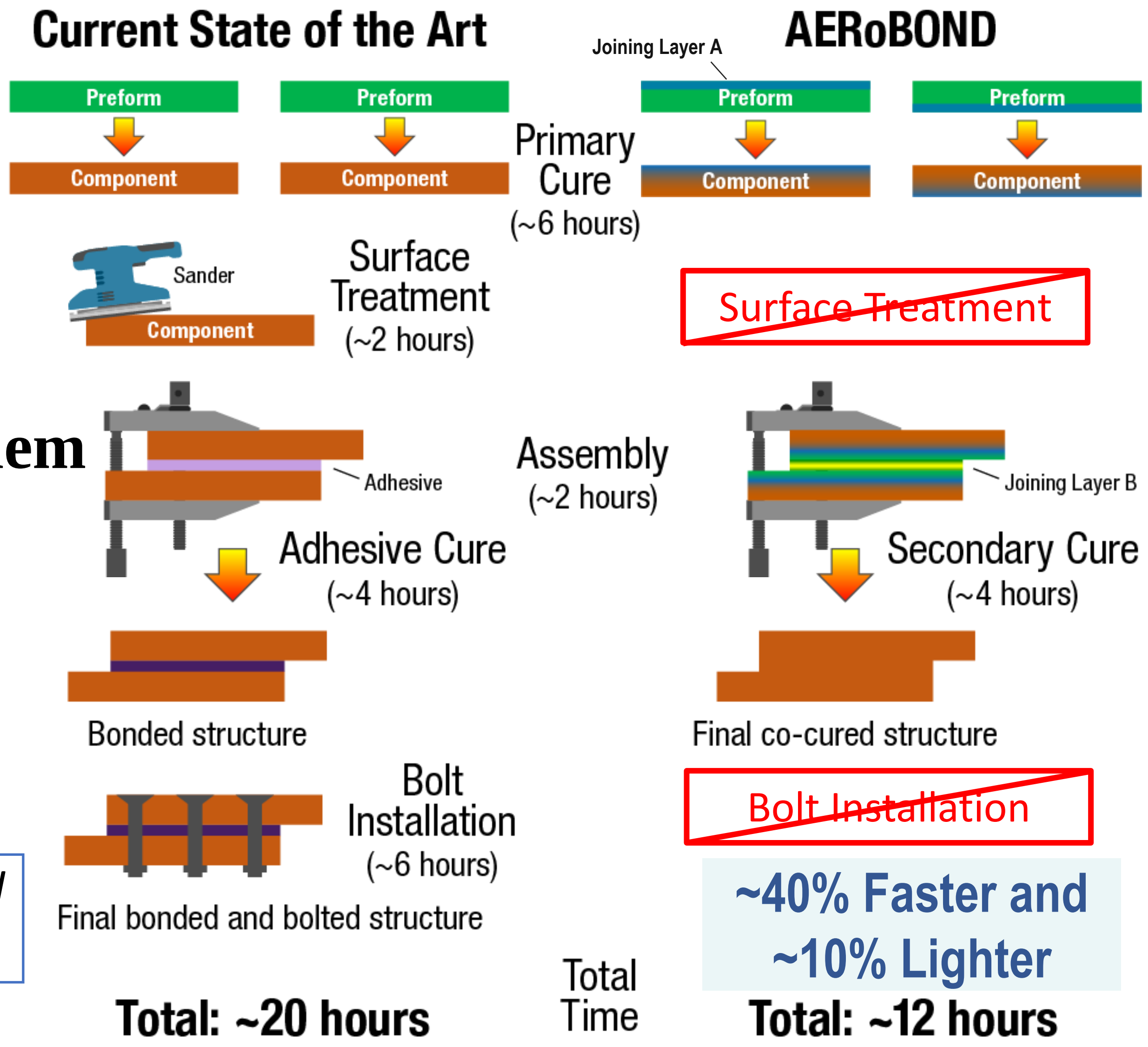
Why is AERoBOND Transformational?

Airframes are assemblies of many parts

- ❖ Composites can be assembled rapidly with adhesives
- ❖ Redundant load path (bolts) is required for certification
- ❖ **Thousands of drilling and installation steps**
- ❖ Fastener installation is **too slow** causing a bottleneck
- ❖ Production rates cannot meet future demand

AERoBOND addresses part of this problem

- ❖ AERoBOND eliminates the need for surface preparation
- ❖ Significantly reduces the reliance on redundant fasteners
- ❖ AERoBOND method projected to be ~40% faster than state-of-art (SoA)
- ❖ AERoBOND proven to have almost equivalent or improved mechanical properties to SoA



"AERoBOND – Enabling Reliable and Rapid Manufacturing for Tomorrow's Aircraft"

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Cure Process Monitoring of Composites

1. T.B. Hudson, P.J. Follis, J.J. Pinakidis, T. Sreekantamurthy, and F.L. Palmieri, “Porosity detection and localization during composite cure inside an autoclave using ultrasonic inspection,” Composites Part A: Applied Science and Manufacturing, 106337, 2021. https://doi.org/10.1016/j.compositesa.2021.106337
2. T.B. Hudson, N. Auwaijan, and F.G. Yuan, “Guided wave-based system for real-time cure monitoring of composites using piezoelectric discs and fiber Bragg gratings/phase-shifted fiber Bragg gratings,” Journal of Composite Materials, Vol. 53, pp. 969–979, 2019. https://doi.org/10.1177/0021998318793512
3. T.B. Hudson and F.G. Yuan, “Automated in-process cure monitoring of composite laminates using a guided wave-based system with high temperature piezoelectric transducers,” Journal of Nondestructive Evaluation, Diagnostics and Prognostics of Engineering Systems, Vol. 1, paper no. 021008, 2018. https://doi.org/10.1115/1.4039230

Cure Process Monitoring of Composites

Challenge:

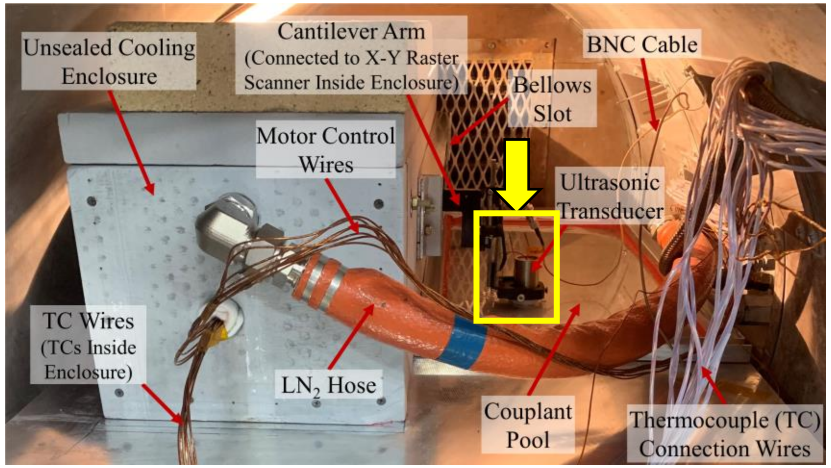
- ❖Composite materials offer many advantages to aerospace applications
- ❖Defects (e.g., porosity) occur during the manufacture of composites
- ❖No direct measurement technique of porosity during cure existed
  - ❖Current inspection processes do not occur until after cure. If defects are present, expensive rework is required (up to scrapping the part).

NASA X-57 All-Electric Experimental Aircraft
Image Credit: NASA/AFRC/Ken Ulbrich
(https://images.nasa.gov/details-AFRC2019-0260-53)

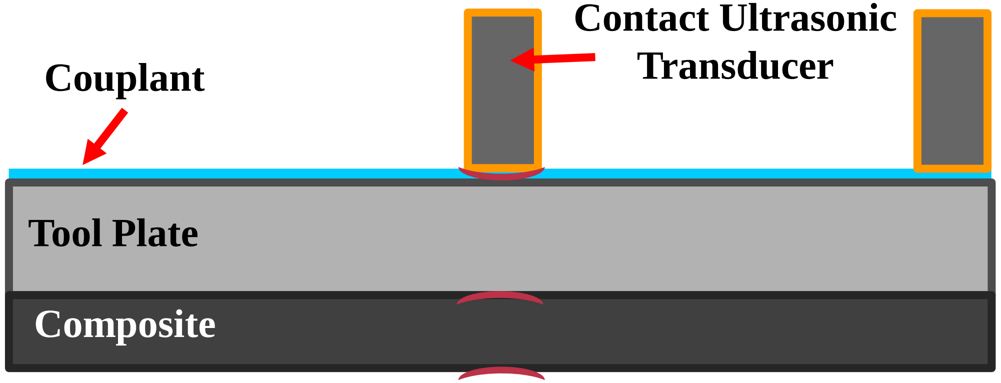
Optical Micrographs Detailing Moderate (left), Low (middle), and High (right) Levels of Porosity

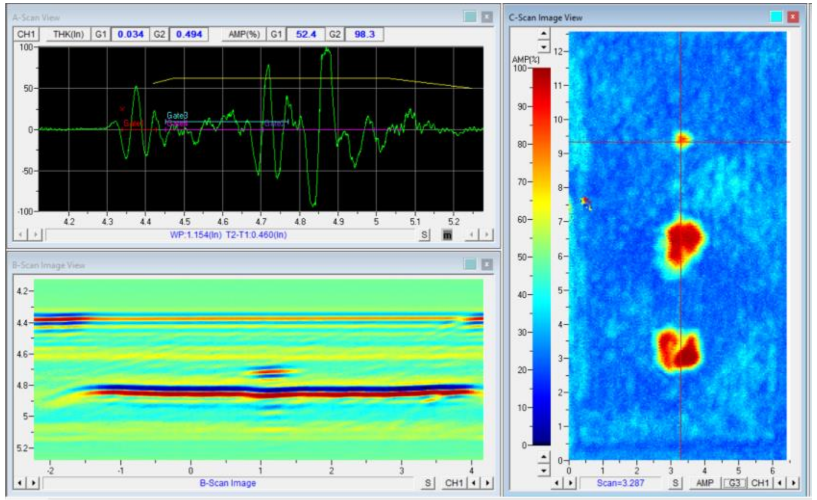
Cure Process Monitoring of Composites (*cont.*)

- ❖ Developed first-of-its-kind inspection system that performs defect detection, localization, and quantification during cure in oven and autoclave.
- ❖ Features:
  - ❖ High spatial resolution cure monitoring of resin state and material properties (in addition to defect detection).
  - ❖ Scalable from research and development to existing production lines.
  - ❖ No change required to current part design and limited changes to processing equipment.
  - ❖ Minor changes to tooling may be required for tool-side inspection of complex geometry.



Scanning system Inside Autoclave Prior to Cure





Ultrasonic Measurements (A-scan, B-scan, and C-scan)

Cure Process Monitoring of Composites (*cont.*)

- Impact:
  - Real-time knowledge of porosity (or other defect) location and quantity during cure.
  - Validation of process models and/or processing parameters during certification.
  - Control of processing parameters during cure based on real-time measurements.
  - ***Results in more efficient process development, shortened certification time, reduction in off-spec parts, and increased production throughput.***
- Applications: Aircraft, launch vehicles, satellite buses, automotive, wind turbine blades, marine, etc.

Summary

- ❖RAMPT
  - ❖Design and manufacturing technologies to increase scale, significantly reduce cost, and improve performance for regeneratively-cooled thrust chamber assemblies.
- ❖AERoBOND
  - ❖Enabling reliable and rapid manufacturing and assembly for tomorrow's aircraft.
- ❖Cure Process Monitoring of Composites
  - ❖First-of-its-kind inspection system that performs defect detection, localization, and quantification during cure.
  - ❖Control of processing parameters during cure based on real-time measurements.

Questions?